AC 2012-3542: IMPACT OF INTEGRATED PRODUCT TEAM COURSE ON SKILL DEVELOPMENT AND WORKPLACE PREPARATION FOR GRADUATING ENGINEERING SENIORS

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Impact of Integrated Product Team course on skill development and workplace preparation for graduating engineering seniors

Introduction

It is well documented that there is a significant national need for engineers, especially in aerospace-related fields.[1,2] This need is primarily driven by the aging workforce at NASA, the Department of Defense, and related industry.[3] NASA reports 28% of its engineers and 45% of its scientists are eligible to retire now and an even larger percentage will be able to retire within the next ten years.[3] With that being said, there is an acute need in Alabama where the Alabama Department of Labor estimated that the demand for engineers in the state would be 1000+ per year for the next decade.[4] In conversation with members of the Huntsville/Madison County Chamber of Commerce, they estimate that approximately 75% of that demand will be in the North Alabama region. Huntsville, dubbed the "Rocket City", is already a high technology hub because of the presence of organizations such NASA's Marshall Space Flight Center, the U.S. Army Aviation and Missile Command, the U.S. Army Aviation and Missile Research Development and Engineering Center as well as branch offices for the all major aerospace and defense contractors. In addition, within the last three years, it has become the headquarters for the U.S. Army Material Command, the Missile Defense Agency, and the Space and Missile Defense Command. The technical focus of these organizations is driving the state's need for engineering talent, especially in North Alabama. As a result, there is a need to develop engineers that possess knowledge, skills, dispositions, and experiences that will lead them to successfully enter the workforce and be prepared for the multi-dimensional environment of the aerospace industry.

In order to prepare students to meet the rigorous demands of the aerospace industry, The University of Alabama in Huntsville (UAHuntsville) College of Engineering has established a *capstone* senior design sequence that provides real-world design experience. The concept of using a *capstone* design course as a summative activity within an engineering program is rooted in the constructivist theory of authentic learning. Authentic learning is a process of creating knowledge through meaningful experiences, such as real-world problem-based activities.[5] Authentic learning experiences can be distilled down to 10 design elements: (1) real-world relevance, (2) use of an ill-defined problem that cannot be easily solved, (3) the need for sustained investigation, (4) the need for multiple sources and perspectives, (5) collaboration, (6) constant reflection, (7) interdisciplinary perspectives, (8) integrated assessment throughout, (9) polished products, and (10) multiple interpretations and outcomes.[6] Therefore, the Accreditation Board for Engineering and Technology in criterion 5, specifies the following requirements with regard to engineering capstone project experiences: "Students must be prepared for engineering practice through a curriculum culminating in a major design experience based on the knowledge and skills acquired in earlier course work and incorporating appropriate engineering standards and multiple realistic constraints."[7]

A 2005 survey of capstone design courses nationwide found that 98 percent of engineering departments have some form of a capstone design course.[8] However, reviewing the results of the survey indicates that the approach taken in the UAHuntsville College of Engineering is unique. The Integrated Product Team (IPT) course, led by The University of Alabama in Huntsville, engages undergraduate scientists and engineers in a multi-university project whose goal is to provide the opportunity for the students to translate stakeholder needs and requirements into viable engineering design solutions via a distributed multidisciplinary team environment. The core of the program is the two-semester *capstone* design experience where undergraduate students in science, engineering, and liberal arts from UAHuntsville, the College of Charleston, and one or more external engineering partners (i.e., Southern University at Baton Rouge, Louisiana or Ecole Supérieure des Techniques Aéronautiques et de Construction Automobile, or ESTACA University in Paris, France) form multidisciplinary competitive teams to design a spacecraft to accomplish a mission to a planetary body of interest to the NASA Discovery/New Frontiers Program office. . Figure 1 shows the breakdown of the team roles and responsibilities. External industry review boards are also formed to provide guidance and feedback throughout the semester and to ultimately choose a winner from the competing teams.

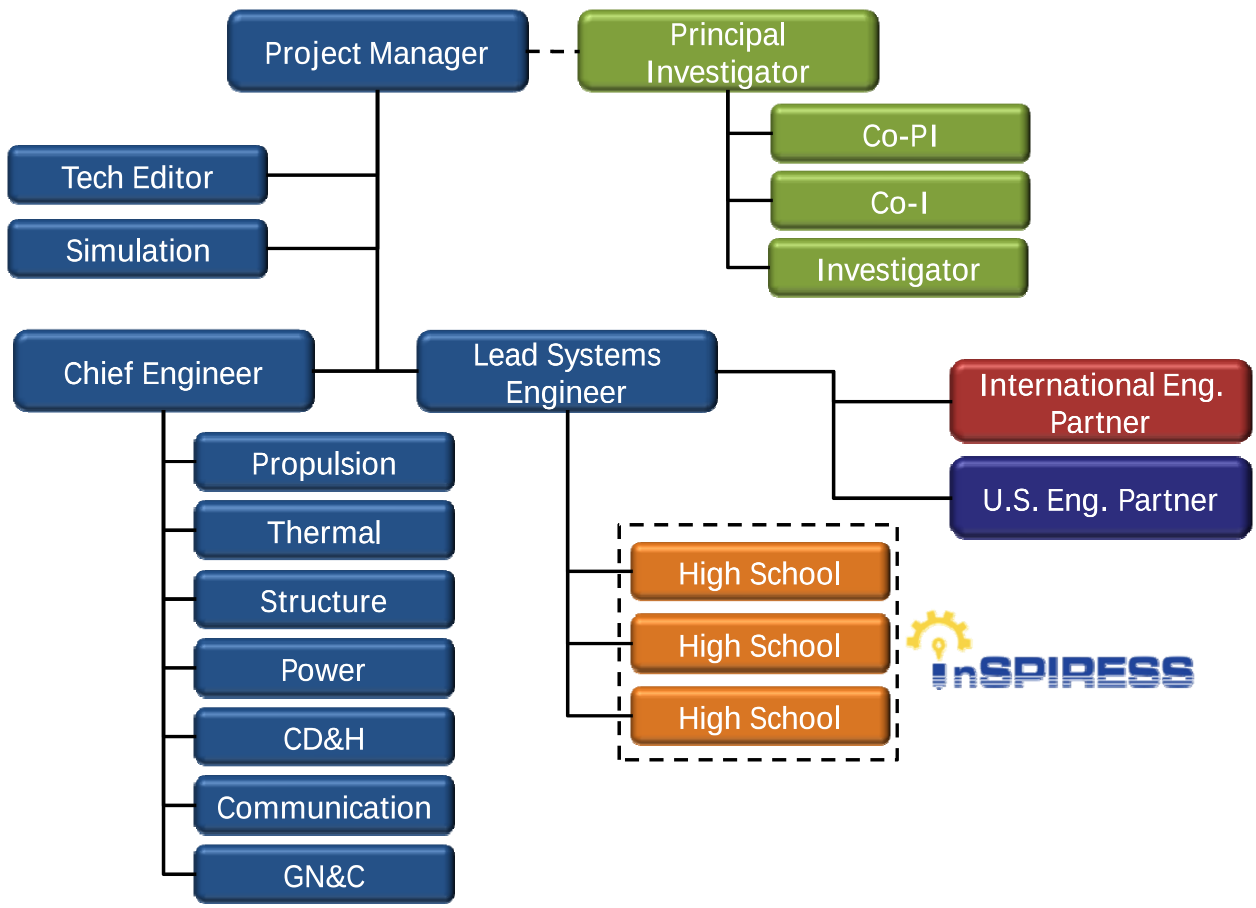

Figure 1. The UAHuntsville Integrated Product Team Model

The IPT capstone design sequence emphasizes four key areas of expertise that are critical for any new scientist/engineer in today's competitive environment: systems thinking, communication, teamwork, and design. These four areas are emphasized over four phases during the two semester sequence: requirements development and trade space evaluation, team formation and mission feasibility study, mission concept study, and final system design.

For systems thinking, students learn the concept of systems-level design and development, taking the stated need from the end-user or customer and developing design requirements, documenting them, and developing design solutions to meet the need. They must understand the total lifecycle of a proposed design and understand the methods for deciding which solution is appropriate for the given criteria. A recent study by the National Research Council cited that the aerospace industry believes the essence of being a good systems engineer “depends on applying all knowledge, including functional and domain knowledge, along with the tools, at the right places in any given program”.[9] The projects for the IPT courses require the application of a student’s domain knowledge in a systems context. Communication is taught via the development of a written proposal, to the customer or end user, of the proposed design solution. Marketing is also employed to "sell" the team's solution to the external review board. Because the project is team-based, students must develop team building skills by learning how to collaborate and integrate elements of the system in order to develop the solution at hand via a distributed integrated product team. Team members can be drawn from several departments within the College of Engineering (i.e., Mechanical and Aerospace Engineering, Industrial and Systems Engineering, and Electrical Engineering)) and non-engineering departments (i.e., English/Technical Editing) as well as from the partner universities (i.e., College of Charleston, Southern University, and ESTACA). The design principle emphasizes subsystem definition and design as well as technical integration of the proposed system solution.

Over the past 18 years, the UAHuntsville faculty charged with teaching the IPT courses have focused primarily on designing the course activities, forging collaborative partnerships with other universities and local industry and organizations. With the design courses secure within the UAHuntsville program of study, the faculty are now turning their attention to refining and revising the project to make it is more beneficial for the students who will be seeking employment in the aerospace industry. To-date, little emphasis has been placed on developing outcome measures to determine the effectiveness of the IPT capstone design course in enhancing student success in the design and engineering of aerospace systems, especially as it relates to graduates serving the specific needs of the local community. Some anecdotal evidence, outside of formal course assessments, has been collected on the UAHuntsville IPT course to evaluate its impact on the students. Several local employers regularly contact the IPT instructors to hire their top graduates; however no definitive measure exists to determine whether the IPT course is achieving the goal of creating a world class engineer capable of transitioning seamlessly into the local workforce. A recent study by Davis et al., suggests that there is a need to match the capstone course objectives within an engineering curriculum to the attributes needed of top quality engineers.[10] As a result, in order to make the IPT project more beneficial, the IPT faculty engaged the UAHuntsville Department of Education to establish an interdisciplinary collaboration in order to learn how to evaluate the current program

The first task of the new collaborative research team was to determine what aspects of the IPT project to assess. While the course assignments, reviews by external review boards, and final reports were all part of the course, there was no evaluation plan to determine if the capstone course had a positive impact on the students. In particular, there were no mechanisms to see how the capstone course impacted motivation, learning, or self-efficacy, which have all been found to be critical factors for successful engineers. Therefore, the research team began by focusing on one set of impacted factors guided by one research question: What impact does the IPT project have on engineering students’ self-efficacy, motivation, learning strategies, and community of learning?

Methodology

In order to answer this question, the research team conducted a quasi-experimental study using a pre-post test evaluation.

Participants: The participants in this study were UAHuntsville undergraduate students majoring in Mechanical Engineering, Aerospace Engineering, or Industrial and Systems Engineering. Two groups of students were involved in this study. The out-of-phase IPT project participants were Mechanical and Aerospace Engineering students who took the IPT sections of MAE 490 in Spring 2011 and MAE 491/492 in Fall 2011. The in-phase IPT participants were Mechanical Engineering, Aerospace Engineering, and Industrial and Systems Engineering students taking IPT sections of MAE 490 and ISE 428 during Fall 2011 and IPT sections of MAE 491 and ISE 429 during Spring 2012. All of these students were completing their capstone design coursework and were 19 years old or older.

In order to evaluate the impact of the IPT project on the students' preparation to enter the workforce, we conducted a quasi-experimental study within the capstone courses involved in the IPT project. The intent was to determine the impact of the authentic, inquiry-based learning experience on students' motivation, attitudes, self-efficacy and other cognitive and metacognitive measures. On the first day of the class, a designated person (DP) outside of the engineering faculty was invited to class to briefly explain the study to the students and invite their participation. Informed consent forms were handed out and students interested in participating were asked to fill them out and return them. The DP provided the students with the surveys. The students completed the survey and returned them to the DP for later evaluation and analysis.

The surveys will be completed three times: pre (August), midterm (December/January), and post (April/May). The per (August) surveys are administered the first day of class and capture student attitudes before the start of the course. The midterm (December/January) surveys were adminstered in December to students that were in their second semester of the IPT sequence, while those administered in January were to students that were coming into the IPT sequence mid-stream (i.e., they had taken the first course prior to fall 2011 and were joining the second class in January 2012) thus we are capturing their attitudes before they have participated in IPT. It should be noted that this is only a handful of students (i..e, 6) Finally, the post (April/May) surveys will be administered to capture the attitudes of the second group of students (i.e., those that started in August or January) after they have complete the IPT course. By completing the surveys three times, we will be able to monitor the impact of participating in a capstone course for two semesters. Also, this will allow us to compare any students that may only take the second course during the spring. The data presented in this paper is only for the pre-post data collected from the out-of-phase group which completed the IPT sequence in December 2011. All raw data was compiled by the evaluation team in the UAHuntsville Department of Education. They inputted and coded the data in SPSS 18.0 and completed all relevant statistical analysis of the data.

During the Fall 2011 administration, the instruments were completed during the first class meeting. During that first class, the project was explained by the education faculty and students were asked to sign a consent form to participate. Those who did participate were provided a paper copy of the instrument which included a unique "student number". The students were given ample time to complete the surveys. They were asked to sign a form beside the number of the instrument in order to correlate the pre- and post-tests. The post-test administration took place during the last class meeting before final exams. As with any attitudinal study implementation, outside variables such as time of day, location, noise, lighting, and individual variables could impact the participants' responses. All measures were taken to limit the number of extraneous factors that could impact their responses. The same procedure was followed except that students were given the instrument packet with the "student number" they were assigned in the first administration and they were allowed to use a "scantron" form instead of circling the answer. The education faculty, who conducted the analysis, were not allowed to see the student number list ensuring that the data was anonymous. The raw data was entered by staff assistants and provided directly to the education faculty for analysis. All future administrations will be implemented using "scantron" forms as a more efficient method of collecting data. Also, a qualitative section composed of one question has been added to the survey.

Instrumentation: This study will utilize the following instruments:

Demographic information. The surveys will also include a simple demographic section that focuses on the students' sex, race/ethnicity, academic standing (i.e., junior or senior) and major.

Motivated Strategies for Learning Questionnaire.[11] was designed to measure college undergraduates' motivation and self-regulated learning as they relate to a specific course. The *MSLQ* consists of 81, self-reported items divided into two broad categories: (1) a *motivation* section and (2) a *learning strategies* section. Items on the MSLQ were scored using a five point Likert-type scale with 1 being "not at all true of me" and 5 being "very true of me." According the MLSQ Manual:

The motivation section consists of 31 items that assess students' goals and value beliefs for a course, their beliefs about their skill to succeed in a course, and their anxiety about tests in a course. The learning strategy section includes 31 items regarding students' use of different cognitive and metacognitive strategies. In addition, the learning strategies section includes 19 items concerning student management of different resources.[11]

The Patterns of Adaptive Learning Scales (PALS)[12] was designed to examine the relationship between learning environment and students' motivation, affect, and behavior. PALS consists of 94, self-reported items divided into five subscales: (1) personal achievement goal orientations; (2) perceptions of teacher's goals; (3) perceptions of the goal structures in the classroom; (4) achievement-related beliefs, attitudes, and strategies; and (5) perceptions of their parents and home life. Items on the PALS were scored using a five point Likert-type scale with 1 being "not at all true" and 5 being "very true".

Findings

A paired-samples t-test was conducted to compare the pre-test to the post-test upon completion of a semester in the capstone course. Table 1 provides the pre- and post-test means and standard deviations in parenthesis as well as the t-score and p-value for the *MLSQ*.

Table 1 Results for MLSQ

MLSQ Subsections	pre-test mean	post-test mean	t-score	p-value
Intrinsic Goal Orientation	4.28 (0.63)	3.88 (0.73)	3.310	0.004*
Extrinsic Goal Orientation	4.09 (0.74)	3.70 (0.67)	2.527	0.210*
Task Value	4.48 (0.52)	4.14 (0.77)	2.713	0.014*
Control of Learning Beliefs	4.44 (0.5)	3.95 (0.71)	3.347	0.003*
Self-Efficacy for Learning and Performance	4.53 (0.55)	4.04 (0.77)	3.003	0.007*
Test Anxiety	2.95 (1.37)	2.82 (0.86)	0.572	0.574
Rehearsal	3.40 (0.68)	3.25 (0.93)	0.721	0.479
Elaboration	3.96 (0.68)	3.69 (0.62)	1.570	0.133
Organization	3.65 (0.66)	3.26 (0.82)	2.071	0.052
Critical Thinking	3.44 (0.77)	3.52 (0.65)	-0.407	0.698
Metacognitive Self-Regulation	3.46 (0.52)	3.18 (0.44)	3.147	0.005*
Time and Study Environment	4.14 (0.37)	3.29 (0.33)	8.133	<0.0005*
Effort Regulation	4.28 (0.66)	3.04 (0.41)	6.116	<0.0005*
Peer Learning	3.47 (0.94)	3.42 (0.99)	0.221	0.827
Help Seeking	3.89 (0.72)	3.69 (0.60)	1.277	0.217

Note: $\alpha = 0.05$; df = 19; * denotes statistical significance

In reviewing the results from the *MLSQ*, the students' mean scores actually went down in each category except "Critical Thinking" (yet the change was not statistically significant). Of the fifteen sub-categories, eight had lower means which were deemed to be statistically significant as indicated by the asterisk. The "motivation" areas where means were statistically lower include:

- "Intrinsic Goal Orientation" measures the student's perceptions of the reasons why he/she is engaging in a learning task and focuses on reasons such as challenge, curiosity, and mastery.
- "Extrinsic Goal Orientation" measures the degree to which the student perceives him/herself to be participating in the task for reasons such as grades, rewards, competition, etc.
- "Task Value" refers to the student's evaluation of how interesting, how important, and how useful the task is and why they are participating in it.
- "Control of Learning Beliefs" refers to the students' beliefs that their efforts to learn will result in positive outcomes.
- "Self-Efficacy for Learning and Performance" includes judgments about one's ability to accomplish a task as well as one's confidence in one's skills to perform the task.

There were also three "learning strategies" scales that were statistically significant including:

- "Metacognitive Self-Regulation" which refers to the awareness, knowledge, and control of cognition.
- "Time and Study Environment" which includes time management for studying and creating an environment conducive to learning.

- "Effort Regulation" includes the students' ability to control their effort and attention in the face of distractions and uninteresting tasks.

The Patterns for Adaptive Learning Scale (PALS) was also completed by the students in the capstone course. Table 2 provides the pre- and post-test means and standard deviations in parenthesis as well as the t-score and p-value for the PALS.

Table 2 Results for PALS

PALS Subsections	pre-test mean	post-test mean	t-score	p-value
Academic Efficacy	3.15 (0.69)	3.85 (0.77)	-3.695	0.002*
Academic Press	2.42 (0.62)	3.37 (0.61)	-7.139	<0.0005*
Academic Self-Handicapping Strategies	1.14 (0.20)	2.14 (0.86)	-5.220	<0.0005*
Avoiding Novelty	1.54 (0.31)	2.73 (0.59)	-8.871	<0.0005*
Cheating Behavior	1.07 (0.23)	1.8 (0.93)	-3.929	0.001*
Disruptive Behavior	1.16 (0.320	2.04 (1.04)	-4.554	<0.0005*
Self-Presentation of Low Achievement	1.33 (0.39)	2.29 (0.77)	-5.805	<0.0005*
Skepticism About the Relevance of School for Future Success	1.32 (0.35)	2.13 (0.86)	-4.192	<0.0005*
Parent Mastery Goal	2.38 (1.22)	3.52 (0.97)	-3.559	0.002*
Parent Performance Goal	1.94 (0.86)	3.15 (0.69)	-4.843	<0.0005*
Dissonance Between Home and School	1.27 (0.63)	2.17 (0.81)	-4.736	<0.0005*
Neighborhood Space	1.76 (0.74)	2.75 (0.81)	-5.024	<0.0005*
Mastery Goal Orientation	3.38 (0.61)	1.84 (0.74)	-4.307	<0.0005*
Performance-Approach Goal Orientation	1.84 (0.74)	2.95 (0.71)	-6.478	<0.0005*
Performance-Avoid Goal Orientation	1.91 (0.75)	2.9 (0.65)	-6.532	<0.0005*
Goal Structure	3.23 (0.93)	3.83 (0.55)	-2.863	0.010*
Performance-Approach Goal Structure	2.47 (0.93)	3.35 (0.64)	-3.782	0.001*
Performance-Avoid Goal Structure	1.89 (0.80)	2.75 (0.59)	-4.089	0.001*

Note: $\alpha = 0.05$; df = 19; * denotes statistical significance

A paired-samples t-test indicated that the scores were significantly higher for the post-test than the pre-test. A review of the meaning of each sub-category can be found in the instruments manual.[12]

Discussion

For this research study, students at the University of Alabama in Huntsville which participate in a two-semester capstone engineering course were asked to complete two psychological assessments to determine the impact of the IPT project on multiple factors. The data presented could be considered the "pilot" study of the evaluation plan as it only features one class of 24 students over one semester of work (only 19 of the 24 students completed both the pre and post surveys).

In reviewing the findings, the psychological assessments provided mixed feedback. The students' scores determined from the MLSQ all showed a drop in every category with eight being significant. Casually looking at the data from this instrument would lead one to think that the capstone course actually has a negative impact on the students' motivation and self-efficacy. However, the findings from this one instrument must be taken within the context of its purpose. The MLSQ was developed to "assess college students' motivational orientations and their use of different learning strategies for a college course". [11] It could easily be hypothesized that since the capstone course is such a unique course due to its roots in authentic and inquiry-based learning that the course itself had an impact on the way students look at college courses. The MLSQ was created to be used with typical college courses. Since the capstone course is atypical with its focus on collaborative, project-based activities, the MLSQ may not have been the most appropriate instrument for this course. The purpose of capstone courses is to provide students with an authentic "segway" into real-world engineering activities with their different stressors. It is very possible that the fact that the scores from the MLSQ went down is actually appropriate since this is such an atypical course. At the same time, the findings may suggest that the students determined the capstone course to also be challenging. Typically, when sub-scores such as "self-efficacy" go down after a course, it may be an indication that the students found the course difficult and challenging.

The PALS results provide a different type of insight. The PALS instrument is "using goal orientation theory to examine the relation between the learning environment and students' motivation, affect, and behavior".[12] Therefore, this assessment focuses on the impact of the learning environment on the student. Of course, the learning environment includes the type of course, course delivery, course activities, sense of community, teacher impact, parental impact, etc. Since the PALS data shows a positive impact on the student, it can be surmised that the uniqueness of the course actually has a positive impact on learning, motivation, affect, and behavior. Each of these aspects are actually more highly correlated to the purposes of the capstone course and the IPT project.

Conclusion

This research study is the first results from a long-term evaluation plan for the IPT course. Over the next few years, the collaborating departments at the UAHuntsville plan to continue to collect data to determine the long-term impact of the IPT course. We are particularly interested to see the impact over the entire two semester capstone course. The IPT faculty plan to use the evaluation data to refine the course to meet the needs of their students while the evaluation team will continue to refine the evaluation plan to be more focused on specific measures.

In reviewing the meaning of the findings, it is still too early to determine the impact of the course on attitudinal outcomes. After one semester of applying these commonly used tools, the research team has determined that these may not be the most appropriate tools to answer the primary question of this project, which is to teach the multi-faceted skills to work within an engineering environment. Therefore, based upon the results of the pilot study, the researchers have determined to begin the process to develop and validate an instrument that will measure the purpose of an authentic learning experience such as IPT. In order to develop such an instrument, a one question open-ended question was added to the survey. The question simply asked, "What knowledge and skills are necessary for an engineer to be successful on a project?" From the responses of this question, the research team plans to begin the development of a set of themes where growth was indicated and connect them to existing engineering standards. Then the education research team will begin the development of the instrument based upon the qualitative research and move forward with the refinement and validation of the instrument.

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